SMC-TR-06-03

AEROSPACE REPORT NO.
TR-2006(8570)-2

Astronomical Instrument Control Using LabVIEW and TCP/IP

20 December 2005

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Prepared for

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This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. FA8802-04-C-0001 with the Space and Missile Systems Center, 2430 E. El Segundo Blvd., Los Angeles Air Force Base, CA 90245. It was reviewed and approved for The Aerospace Corporation by J. A. Hackwell, Principal Director, Space Science Applications Laboratory. Michael Zambrana was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

Michael Zambrana
SMC/AXE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. **PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

1. REPORT DATE ***(DD-MM-YYYY)*** 20-12-2005	**2. REPORT TYPE**	**3. DATES COVERED** ***(From - To)***

4. TITLE AND SUBTITLE

Astronomical Instrument Control Using LabVIEW and TCP/IP

5a. CONTRACT NUMBER
FA8802-04-C-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

C. C. Venturini and S. M. Mazuk

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

The Aerospace Corporation
Laboratory Operations
El Segundo, CA 90245-4691

8. PERFORMING ORGANIZATION REPORT NUMBER

TR-2006(8570)-2

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Space and Missile Systems Center
Air Force Space Command
2450 E. El Segundo Blvd.
Los Angeles Air Force Base, CA 90245

10. SPONSOR/MONITOR'S ACRONYM(S)
SMC

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
SMC-TR-05-03

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Aerospace Corporation has developed a near-infrared and visible spectrograph that is used for astronomical observations at Lick Observatory's 3-m telescope. This report describes the instrument control and data handling system, which employs a unique client-server TCP/IP communication model. The control and data acquisition system allows for extensive modifications and has simplified the system design.

15. SUBJECT TERMS
instrumentation, infrared astronomy, LabVIEW, V-NIRIS, ethernet, TCP/IP, IDL, sockets

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON** Catherine Venturini
a. REPORT UNCLASSIFIED	**b. ABSTRACT** UNCLASSIFIED	**c. THIS PAGE** UNCLASSIFIED		4	**19b. TELEPHONE NUMBER** ***(include area code)*** (310)336-5923

Astronomical Instrument Control Using LabVIEW and TCP/IP

by

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Category:
R&D/Lab Automation

Products Used:
LabVIEW™ 7.0, 7.1

The Challenge:
Design a data acquisition and control system that is hardware independent, easily integrates with non-LabVIEW code, and provides a software architecture that is extensible to accommodate instrument upgrades.

The Solution:
Use a client-server TCP/IP communication model where LabVIEW is the server and the client is a commercial off the shelf (COTS) product or internally developed system where the sockets protocol is defined. The client effectively sends/receives information to/from the server depending on user-defined requirements for instrument control.

Background

The Aerospace Enhanced Near-Infrared and Visible Imaging Spectrograph is a long-slit spectrograph that covers the wavelength range from 0.38-2.5 micrometers. It uses two 1024x512 HcCdTe focal-plane arrays (FPAs) for the Near-IR (NIR), and one 1024x256 deep depleted Si FPA for the visible wavelengths. Each FPA is fed by a separate camera, collimator and grating. A common slit and field lens ensures that all three channels of the spectrograph view the same field simultaneously, with beam splitters to separate the wavelengths to each array. The slit jaws are reflective, allowing a CCD camera to image the light not passing into the spectrograph for guiding, and provides an exact view of what is observed by the spectrograph. The spectrograph is used primarily for astronomical observations at Lick Observatory's Shane 3-meter telescope located in Mt. Hamilton, CA.

The control system for the instrument has several requirements. The system is to be used for several years, spanning multiple operating system and computer upgrades. The system has to be hardware independent, e.g. requiring no plug-in boards. The instrument design allows for upgrades to the hardware, thus the software architecture must be extendable to accommodate hardware when the drivers do not use a public communications protocol.

Development of the instrument control system

Since the data analysis software for the instrument was entirely written in Research Systems Inc. Interactive Data Language (IDL), and all the team members were familiar with the language, we had to develop a system that would let us use IDL as the main control system and data analysis but also accommodate the fact that LabVIEW was controlling the instrument hardware. We needed a simple way to pass information between the two programs that would satisfy the system requirements.

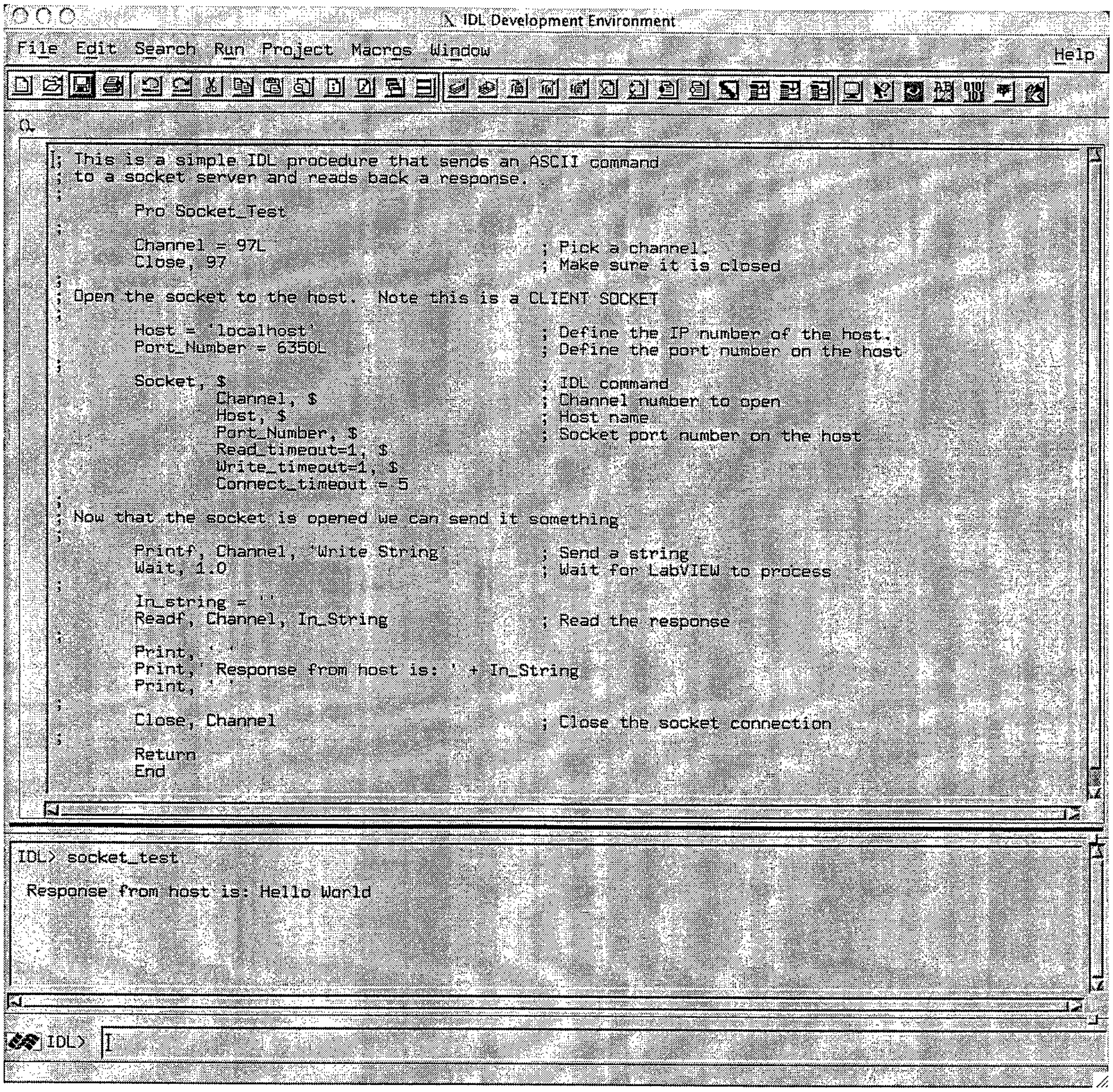
Both IDL and LabVIEW implement the Unix socket protocol, enabling network communications with no additional hardware requirements. Sockets provide a lossless bi-directional protocol, which is required for an instrument control application. IDL implements client-side sockets only, while LabVIEW is creating a server socket and communicating with the IDL process, which uses a client connection. Since IDL and LabVIEW are both running as applications on top of the operating system (OS), this insulates us somewhat from changes in the underlying OS.

The system design implication of going to a socket communication architecture is that all devices must connect to the local area network (LAN). Devices can be direct connected or can use interface conversion boxes, e.g. Ethernet-to-serial. The communications protocols must be clearly documented as well, since the socket standard only defines the interface and not the protocol. The manufacturer for commercial off the shelf (COTS) products defines the protocols, or they can be developed internally for lab-fabricated controllers.

The first implementation of this protocol was with the commercial CCD camera used as the visible focal plane. Since the camera came with LabVIEW drivers, we readily created an application that handled all the camera control functions. We developed a simple set of string commands that would be used to communicate between IDL and LabVIEW. Once the client initiated the TCP/IP connection with the server, then the commands or strings could be passed back and forth between the programs until the connection was closed.

Idl is a sequential execution environment so the client side application is a series of commands executed in order. The LabVIEW server application is based on the Producer/Consumer Data Design Pattern. The Producer Loop contains the TCP Read. Data strings in the buffer sent by IDL is read using TCP Read and then passed to a queue. The Consumer Loop parses the data string sent through the queue and then executes the camera function specified in the string command. When complete with the camera function, LabVIEW sends a string with status information to the buffer via TCP Write. This lets the LabVIEW application handle all the camera control functions, as well as communicate with the IDL-based control program via the socket connection. A simplified example of using this protocol is shown in Figure 1 and 2. Figure 1 is the client-side application in IDL and Figure 2 is the corresponding server-side application in LabVIEW.

One advantage of this approach is that we are able to tailor the communications protocol to meet our specific operational needs. Also this allows us to run both the client-side and server-side applications on the same computer system, but they can be readily moved to separate machines as performance needs change. For our particular application we used IDL and LabVIEW, but this can be extended to any COTS software product or internally developed code and LabVIEW. For example, this type of socket protocol could be incorporated into a C, Visual Basic, or Java Application, or using a COTS package, e.g. Invensis Systems, Inc. Wonderware, LabWindows. The socket protocol is available on Windows, Unix, Mac OS X, and Linux systems thus allowing one to create not only hardware independent but also platform independent software.



```
; This is a simple IDL procedure that sends an ASCII command
; to a socket server and reads back a response.
;
        Pro Socket_Test
;
        Channel = 97L                           ; Pick a channel.
        Close, 97                               ; Make sure it is closed
;
; Open the socket to the host.  Note this is a CLIENT SOCKET
;
        Host = 'localhost'                      ; Define the IP number of the host.
        Port_Number = 6350L                     ; Define the port number on the host
;
        Socket, $                               ; IDL command
                Channel, $                      ; Channel number to open
                Host, $                         ; Host name
                Port_Number, $                  ; Socket port number on the host
                Read_timeout=1, $
                Write_timeout=1, $
                Connect_timeout = 5
;
; Now that the socket is opened we can send it something
;
        Printf, Channel, 'Write String'         ; Send a string
        Wait, 1.0                               ; Wait for LabVIEW to process
;
        In_string = ''
        Readf, Channel, In_String               ; Read the response
;
        Print, ' '
        Print,' Response from host is: ' + In_String
        Print, ' '
;
        Close, Channel                          ; Close the socket connection
;
        Return
        End
```

```
IDL> socket_test

 Response from host is: Hello World
```

```
IDL>
```

Figure 1: This is an example of an IDL client-side procedure that sends an ASCII command to the socket server, LabVIEW, and then reads back a response from the socket server. The client-side procedure opens and closes the socket connection. This assumes that both client and the server are sending ASCII strings that are terminated by CR/LF sequences. This is not an issue if client and the server are the same architecture, but may not hold if host is a different type, e.g. Unix. Binary communication is also possible down a socket connection, however for the binary case one doesn't have a terminator to signal EOL on reads.

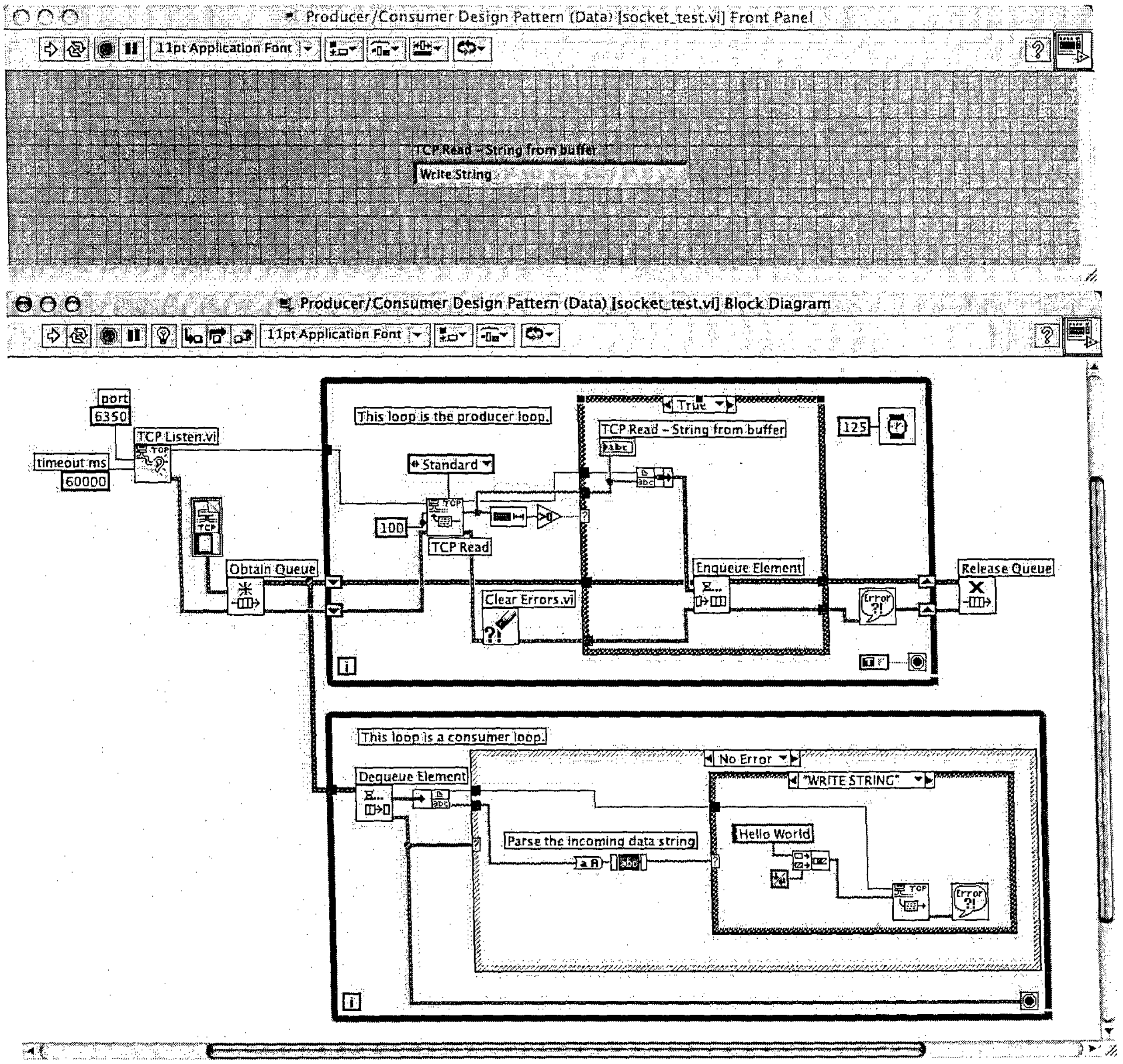

Producer/Consumer Design Pattern (Data) [socket_test.vi] Front Panel
11pt Application Font
TCP Read - String from buffer
Write String
Producer/Consumer Design Pattern (Data) [socket_test.vi] Block Diagram
11pt Application Font
port
6350
TCP Listen.vi
timeout ms
60000
This loop is the producer loop.
Standard
100
TCP Read
True
TCP Read - String from buffer
125
Obtain Queue
Clear Errors.vi
Enqueue Element
Release Queue
This loop is a consumer loop.
Dequeue Element
No Error
"WRITE STRING"
Parse the incoming data string
Hello World
Error ?!

Figure 2: This is the example server side LabVIEW application. LabVIEW listens on the port specified under TCP Listen.vi until the connection is established. Once established, TCP Read.vi is used to read data from the socket buffer. If something is in the buffer it is then processed and a specified action occurs.

LABORATORY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Laboratory Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual organizations:

Electronics and Photonics Laboratory: Microelectronics, VLSI reliability, failure analysis, solid-state device physics, compound semiconductors, radiation effects, infrared and CCD detector devices, data storage and display technologies; lasers and electro-optics, solid-state laser design, micro-optics, optical communications, and fiber-optic sensors; atomic frequency standards, applied laser spectroscopy, laser chemistry, atmospheric propagation and beam control, LIDAR/LADAR remote sensing; solar cell and array testing and evaluation, battery electrochemistry, battery testing and evaluation.

Space Materials Laboratory: Evaluation and characterizations of new materials and processing techniques: metals, alloys, ceramics, polymers, thin films, and composites; development of advanced deposition processes; nondestructive evaluation, component failure analysis and reliability; structural mechanics, fracture mechanics, and stress corrosion; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle fluid mechanics, heat transfer and flight dynamics; aerothermodynamics; chemical and electric propulsion; environmental chemistry; combustion processes; space environment effects on materials, hardening and vulnerability assessment; contamination, thermal and structural control; lubrication and surface phenomena. Microelectromechanical systems (MEMS) for space applications; laser micromachining; laser-surface physical and chemical interactions; micropropulsion; micro- and nanosatellite mission analysis; intelligent microinstruments for monitoring space and launch system environments.

Space Science Applications Laboratory: Magnetospheric, auroral and cosmic-ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; infrared surveillance, imaging and remote sensing; multispectral and hyperspectral sensor development; data analysis and algorithm development; applications of multispectral and hyperspectral imagery to defense, civil space, commercial, and environmental missions; effects of solar activity, magnetic storms and nuclear explosions on the Earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation, design, fabrication and test; environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions, and radiative signatures of missile plumes.